# Sustainable Aviation Fuel

## The Perspective of an Aircraft Manufacturer - Boeing


Jean-Philippe (JP) Belières, Ph.D.
Boeing Commercial Airplanes -Technical Fellow
*Propulsion System Division - Engines & Fuels*


Topsoe Catalysis Forum

*Munkerupgaard, Denmark*

*September 12-13, 2023*

COPYRIGHT © BOEING 2023



## Table of Contents



COPYRIGHT © BOEING 2023 • 



Table of Contents



COPYRIGHT © BOEING 2023 

# Boeing Supports the Industry’s Commitment to Reach Net Zero Carbon Emissions by 2050

“Global civil aviation operations will achieve net-zero carbon emissions by 2050, supported by accelerated efficiency measures, energy transition and innovation across the aviation sector and in partnership with governments around the world.”

## COMMITMENT TO FLY NET ZERO 2050

ATAG

*5 October 2021*

As the global community emerges from the pandemic and the aviation sector rebounds from the worst crisis in its history, we will build on the success of previous sustainability efforts to push towards the third era of air transport: net-zero carbon global connectivity.

Scientific consensus shows that the Paris Agreement 1.5°C goal would greatly reduce the severity of climate change damage. It is imperative that all sections of society and business set course to support achievement of this goal. The collective air transport sector raises its ambition with a new long-term climate commitment:

- **Global civil aviation operations will achieve net-zero carbon emissions by 2050, supported by accelerated efficiency measures, energy transition and innovation across the aviation sector and in partnership with governments around the world.**

This goal is ambitious and challenging for air transport. It will require coordinated efforts within the aviation industry and from partners, particularly strong support from governments and the energy sector. The goal will be underpinned by a commitment to joint and cooperative action between all stakeholders. Waypoint 2050 outlines a number of key elements to achieve the decarbonisation of air transport, including:

1. Increasing use of sustainable aviation fuels (SAF) and a transition away from fossil fuels by mid-century as part of a wider aviation energy shift including low-carbon electricity and green hydrogen.
2. Research, development and deployment of evolutionary and revolutionary airframe and propulsion systems, including the introduction of electric and / or hydrogen powered aircraft.
3. Continued improvements in efficiency of operations and infrastructure across the system, including at airports and by air navigation service providers.
4. Investment in high-quality carbon offsets in the near-term and carbon removal opportunities to address residual $CO_2$ emissions in the longer-term. In this regard, the industry reaffirms its full support for the International Civil Aviation Organization (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) as an effective transitional measure to stabilise net emissions from international aviation.

Across the sector, we are already undertaking a vast range of activities to reduce aviation $CO_2$ emissions. Our unwavering commitment to respond to the challenge of climate change has not abated despite the crisis we have faced. To achieve net-zero, the sector will require a supportive policy framework from governments focused on innovation rather than cost-inefficient instruments such as uncoordinated taxes or restrictive measures, as well as a robust and full commitment from the energy industry and other stakeholders. As support at the global level is critical, we urge ICAO member states to support the adoption of a long-term aspirational climate goal at the 41st ICAO Assembly in 2022.

Many long-term solutions require an acceleration of activity in the next decade, particularly the deployment of SAF. Some, such as continued efficiency gains, improvements in air traffic management and the implementation of CORSIA, can provide early climate action whilst longer-term measures are developed.

We are committed to ensuring that aviation in 2050 will be able to meet the needs of over 10 billion passengers, connecting the world safely, securely and importantly, sustainably. Further details can be found at www.aviationbenefits.org/FlyNetZero

| | | |
|---|---|---|
| **Luis Felipe de Oliveira**<br>Director General | CANSO<br>**Simon Hocquard**<br>Director General | IATA<br>**Willie Walsh**<br>Director General |
| IBAC<br>**Kurt Edwards**<br>Director General | **Jan Pie**<br>Chair | **Pete Bunce**<br>President and CEO |

Supported by innovation and action throughout the supply chain:

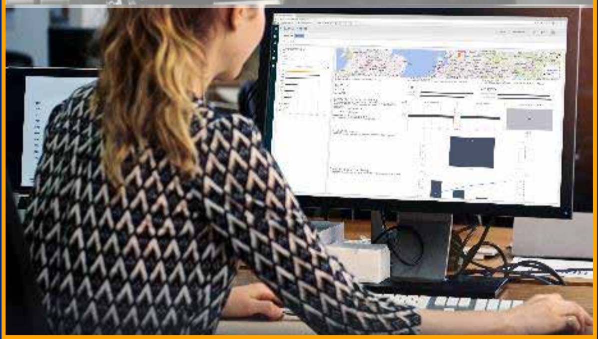
| | | | | |
|---|---|---|---|---|
| AIRBUS<br>**Guillaume Faury**<br>Chief Executive Officer | BOEING<br>**Stan Deal**<br>President and CEO | ATR<br>**Stefano Bortoli**<br>Chief Executive Officer | **Gaël Méheust**<br>President and CEO | **John S. Slattery**<br>President and CEO |
| **Christopher Calio**<br>President | **Warren East**<br>Chief Executive Officer | SAFRAN<br>**Olivier Andriès**<br>Chief Executive Officer | EMBRAER<br>**Francisco Gomes Neto**<br>President and CEO | Collins Aerospace<br>**Stephen Timm**<br>President |

## GETTING TO NET ZERO BY 2050?

# BOEING DECARBONIZATION STRATEGIES

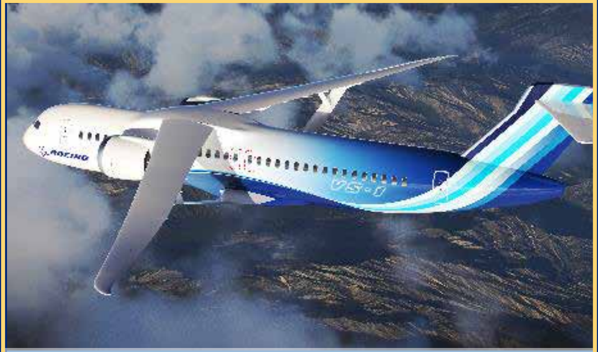
### FLEET RENEWAL


### OPERATIONAL EFFICIENCY



### RENEWABLE ENERGY


### ADVANCED TECHNOLOGY



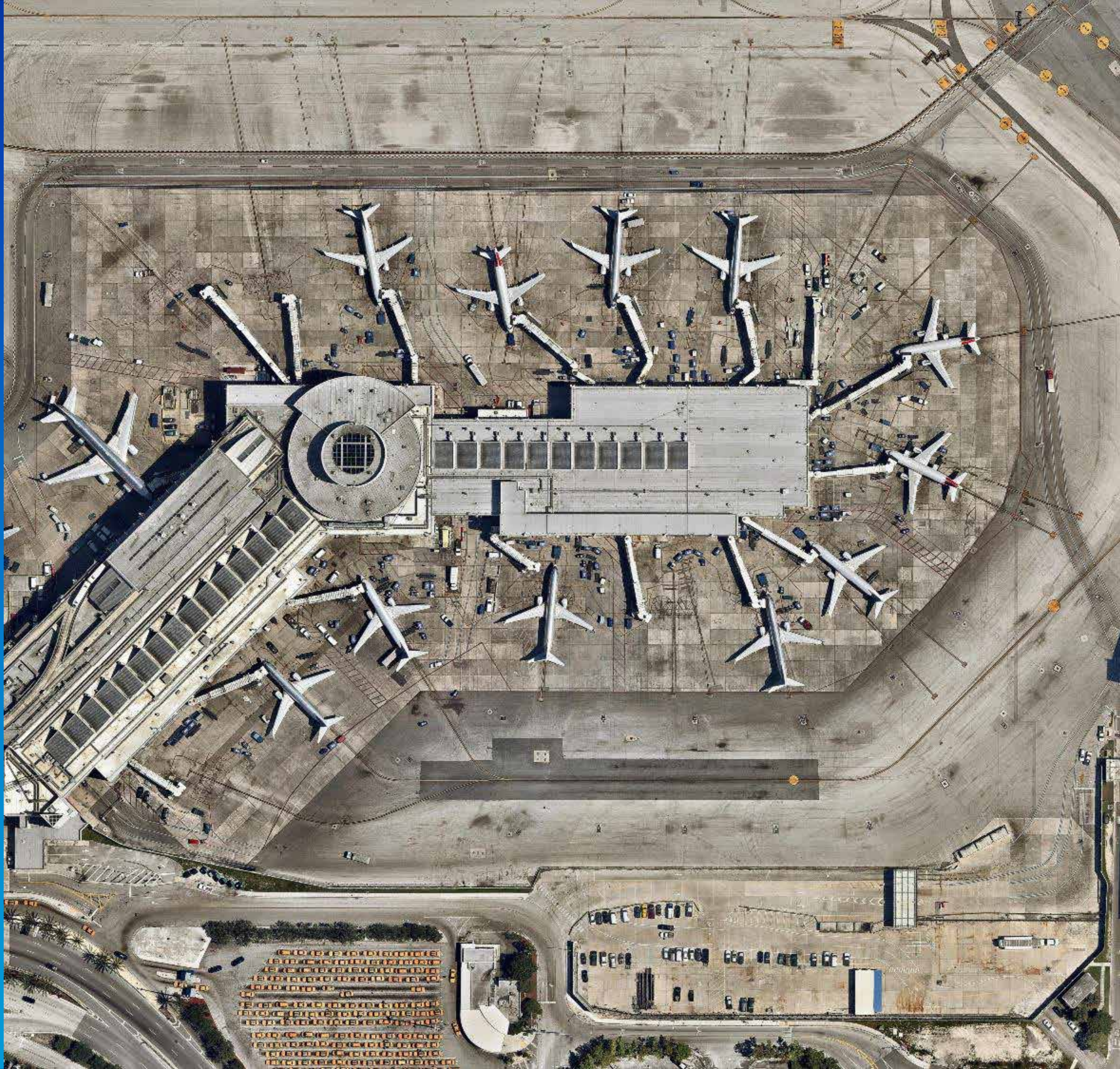
CORSIA Carbon Offsetting and Reduction Scheme for International Aviation

COPYRIGHT © BOEING 2023 

# FACT

Sustainable Aviation Fuel (SAF) offers the largest potential to reduce carbon emissions over the next 30-years across all aviation segments.

Blended SAF is available now.



# FACT

Boeing has committed all its commercial airplanes will be compatible with 100% SAF by 2030



# Table of Contents

# SAF is not new to Boeing, we started in 2008


COPYRIGHT © BOEING 2023 

# Boeing: 15-years in partnership for developing SAF

2009
Co-founded Sustainable Aviation Fuel Users Group (SAFUG)

2010
Boeing supports the supersonic flight of a U.S. Navy F/A-18 on a 50/50 SAF blend - U.S. Navy photo

2014
Proposed and partnered with Neste on ASTM approval of Green Diesel pathway


2018
First commercial airplane test using 100% paraffinic SAF

2018
Launched program for biofuel delivery flights from Boeing Delivery Centers

2022
2 million gallons of SAF procured for operations

2023
Founding Partner in UA Sustainable Flight Fund

2023
Developed jet reference fluid to test for 100% SAF compatibility

2008 2010 2012 2014 2016 2018 2020 2022 2024

2008
First SAF test flight


2011
Led research approval of HEFA pathway

2011
First regional multi-stakeholder roadmaps in the US and Australia

2012
Used biofuel on every ecoDemonstrator program since 2012

2021
Committed to deliver 100% SAF capable airplanes by 2030

2021
Boeing-SkyNRG partnership

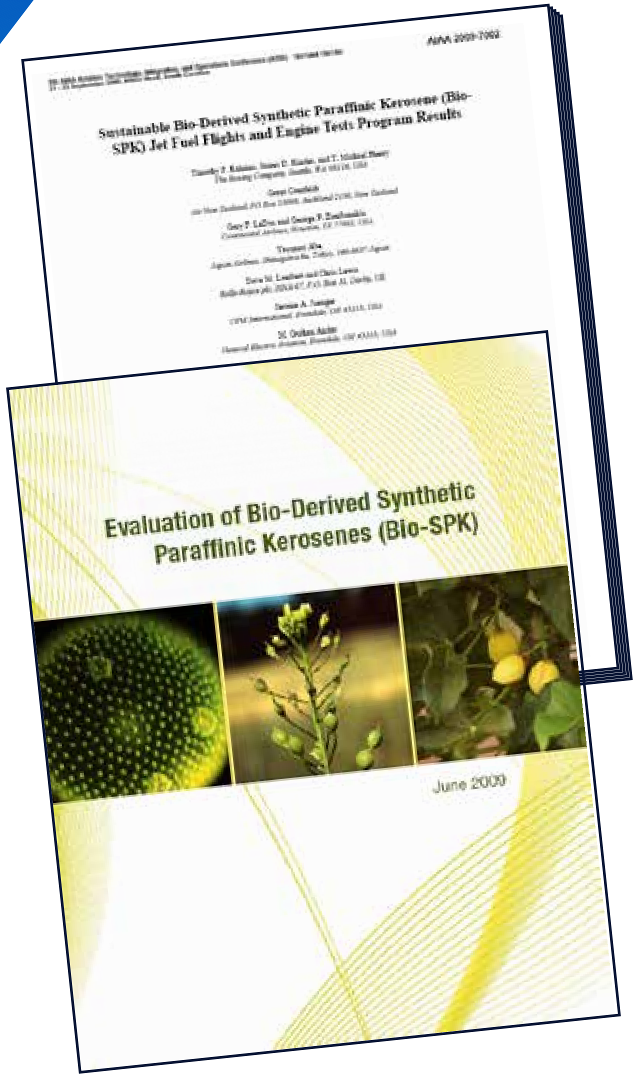
2021
Partnered with United Airlines on first passenger flight with 100% SAF in one engine and Rolls-Royce on 100% SAF flight

2021-2022
Partnered with NASA to test the emissions of SAF

2023
5.6 million gallons of SAF procured for operations

COPYRIGHT © BOEING 2023 • 

# We Have Published Synthetic Fuel Test Results




- *Paris Air Show Executive Summary – June 2009*
- *AIAA Technical Conference Paper – September 2009*
- *ASTM Research Report for Annex 2 – May 2010*

Including data on 100% SAF

COPYRIGHT © BOEING 2023 

# First commercial airplane test using 100% SAF – March 3, 2017

2018 EcoDemonstrator
777 Freighter

In Partnership with
FedEx Express


- Consumed approximately 70,000 USG of 100% HEFA, and 165,000 USG of blended fuel 30/70 (reclassified as Jet A, with ~ 10% Aromatics)
- Selected flights used 100% HEFA in all tanks
- The RM tank had 100% HEFA throughout the entire program
- All systems were compatible with 100% HEFA and functioned as designed
- 100% HEFA performed the same or better than Jet A
- No leaks were observed throughout the duration of the program
- Refueling equipment had no issues with 100% HEFA

# Going from using Blended SAF to 100% SAF takes a team

We are already putting the team together

100% SAF Compatibility Supplier Symposium – Seattle, April 2023

COPYRIGHT © BOEING 2023

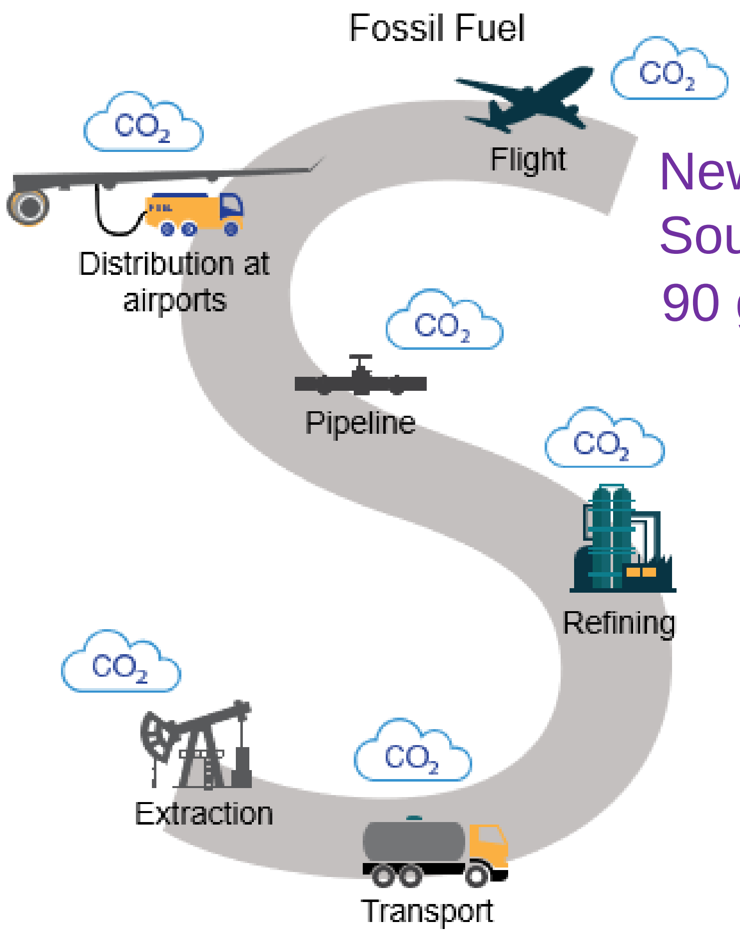


Table of Contents



COPYRIGHT © BOEING 2023 

# Fossil Fuel causes new $CO_2$ to enter the atmosphere

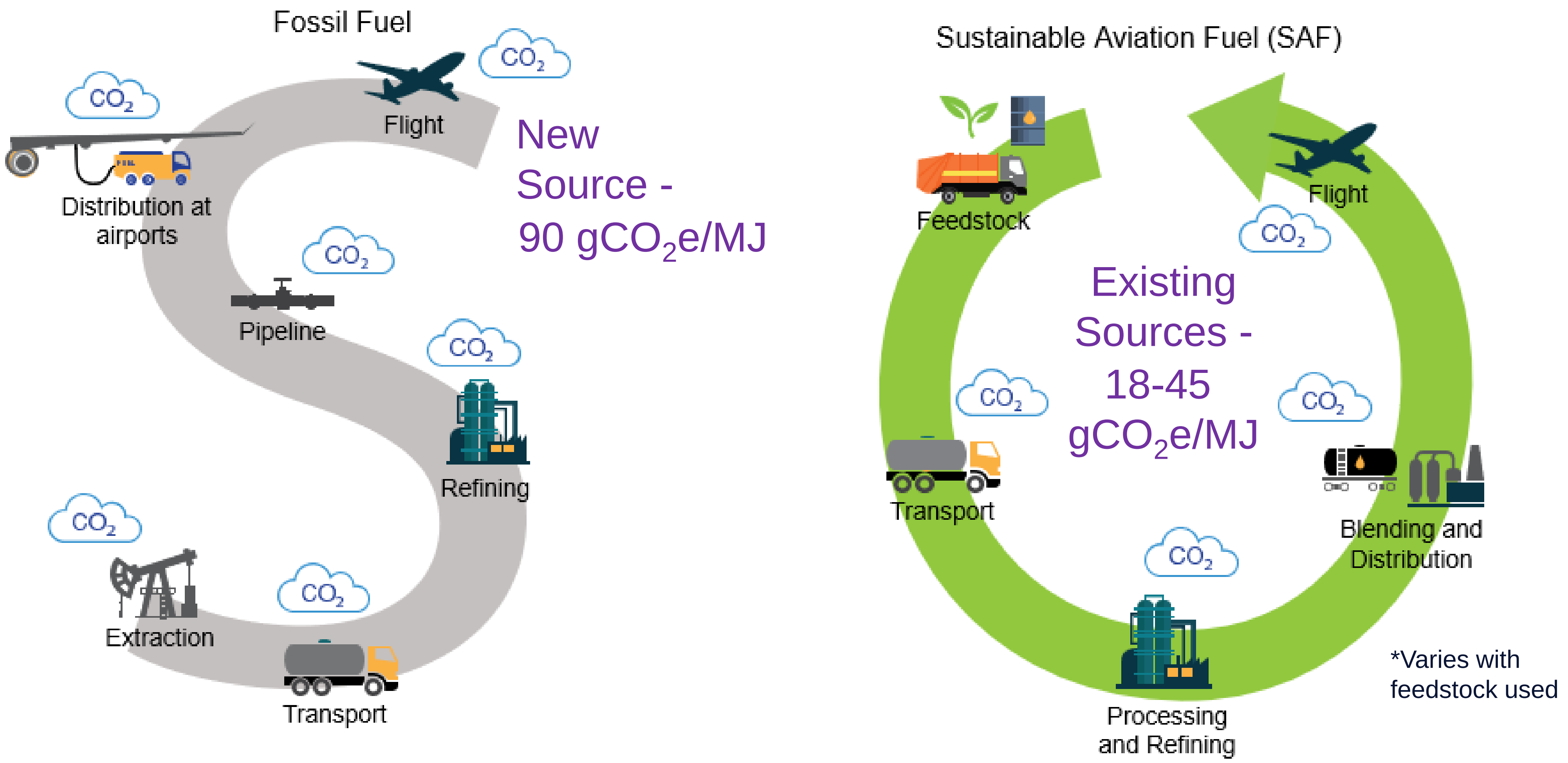



New
Source -
90 $gCO_2e/MJ$

COPYRIGHT © BOEING 2023 

gCO2e/MJ - grams of $CO_2$ equivalent per megajoule

# The SAF Lifecycle Advantage – It's like recycling



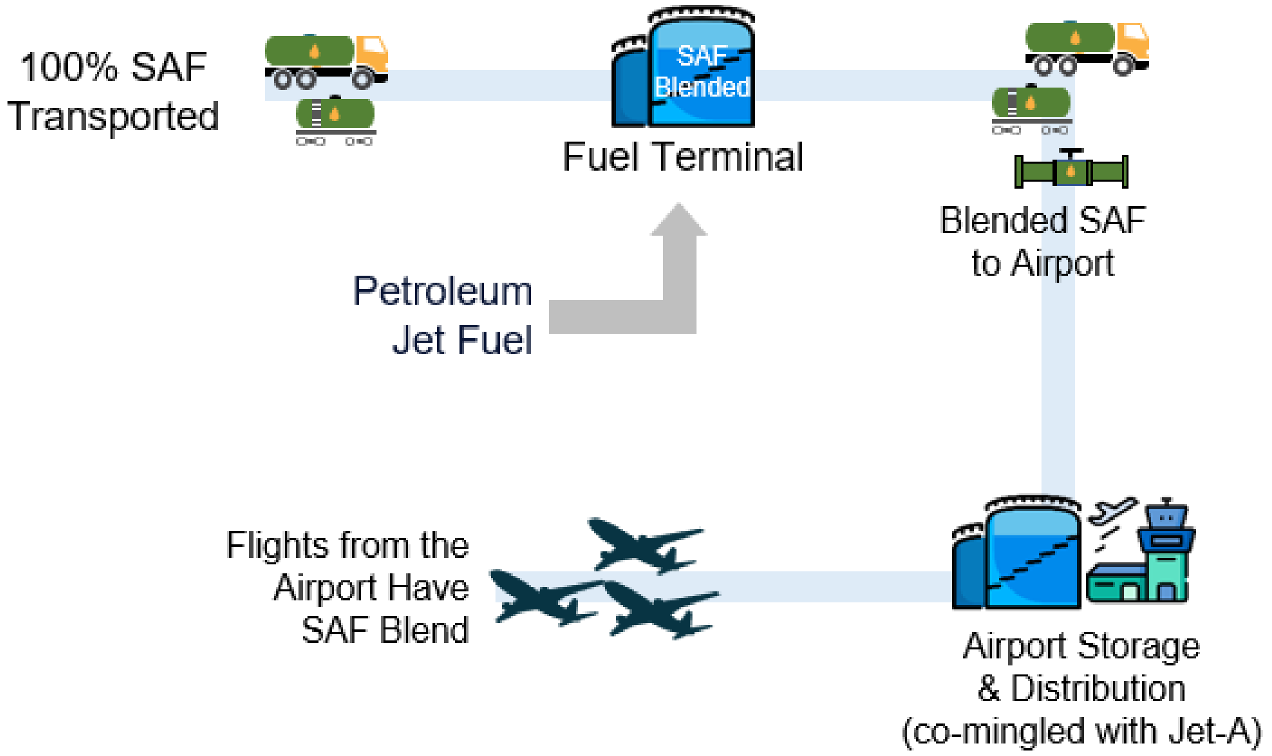

COPYRIGHT © BOEING 2023 • 

$gCO2e/MJ$ - grams of $CO_2$ equivalent per megajoule

# Key features of SAF?

- Made from non-petroleum feedstocks (waste agricultural products, waste cooking oil, fats, and certain crops)
- Equivalent to Jet A/A-1:
  - **Meets ASTM standard D7566**
  - Blends up to 50% approved
  - No special approval needed for use on Boeing airplanes
- SAF usage can result in up to four times lower lifecycle gCO2e/MJ than fossil Jet-A

## No new infrastructure needed; co-mingles with petroleum Jet-A




COPYRIGHT © BOEING 2023 •

# Flies Like Jet A/A-1

No change in flight performance from using SAF blended with petroleum jet fuel

**Evaluation underway to assess the routine use of 100% SAF**



Table of Contents

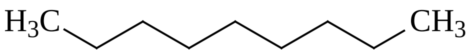


COPYRIGHT © BOEING 2023 

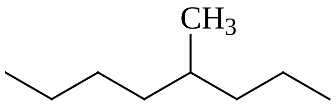
# Chemistry of “typical” jet fuel (kerosene)

***Carbon Length ~ C10-C16***

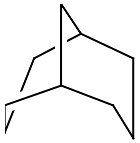
**Paraffins**
**75%-95%**




***Normal Paraffins***

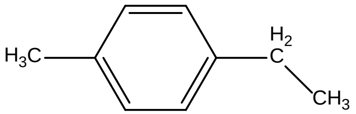


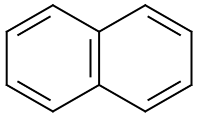

***Iso-paraffins***



***Cyclic Paraffins***

**Aromatics**
**≤ 25% (vol)**



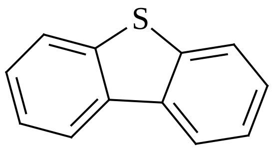



**100% Paraffinic Synthetic Fuel**

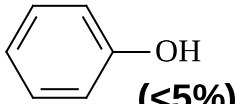
**Fully Formulated Synthetic Fuel**

**100% SAF**

**Sulfur, Nitrogen, Oxygen Containing Compounds**

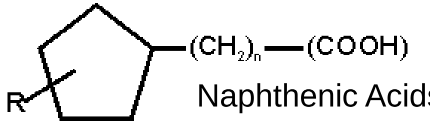



Mercaptans, sulfides, disulfides and thiophenes



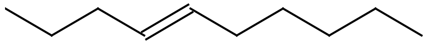

**(<5%)**

Acids, phenols, etc.




Naphthenic Acids - Organic acids that originate from the crude oil

**Olefins**



COPYRIGHT © BOEING 2023 • 

# Evaluation phase to set our requirements

- **We are kicking off an evaluation phase** (Not Qualification or Certification)
- **We are embarking on a new journey** – blazing a new path forward
- **Our approach enables the widest possible future supply of 100% SAF**
- **This industry imperative affects us all**

COPYRIGHT © BOEING 2023 • 

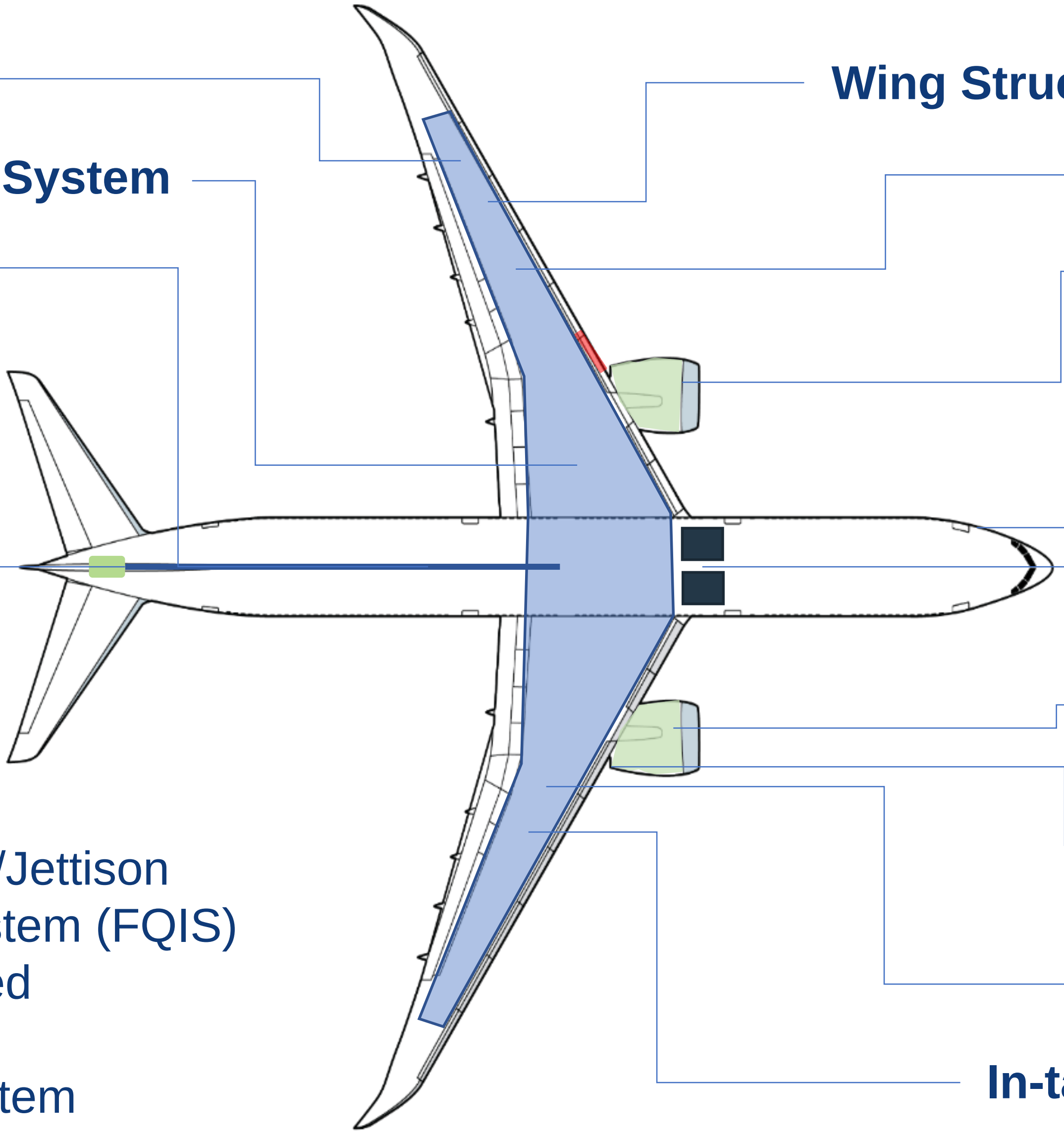
# Three focus areas

Materials Compatibility

Main Engine and APU Compatibility

Fuel & Interfacing Components Compatibility

# SAF areas for review




**Fuel System Defined as:**

Fuel Tankage
Fuel Vent
Engine Feed
Fuel Transfer/Refuel/Defuel/Jettison
Fuel Quantity Indicating System (FQIS)
Auxiliary Power System Feed
Fuel Management
Flammability Reduction System

COPYRIGHT © BOEING 2023 

# Reference fuels and fully formulated fuels

- The concept of Jet Reference Fluid (JRF) is not novel, several exist and have been used in the past, e.g. ASTM D471, TT-S-735, AMS2629

- No single fluid will satisfy all envelope performance and fit for purpose properties

- Need to define Jet Reference Fluids (JRFs) that will target specific properties of interest

- JRFs made from mixtures of commercially available compounds offer full control over composition and can be easily replicated
    - Such JRFs can be used for material compatibility testing

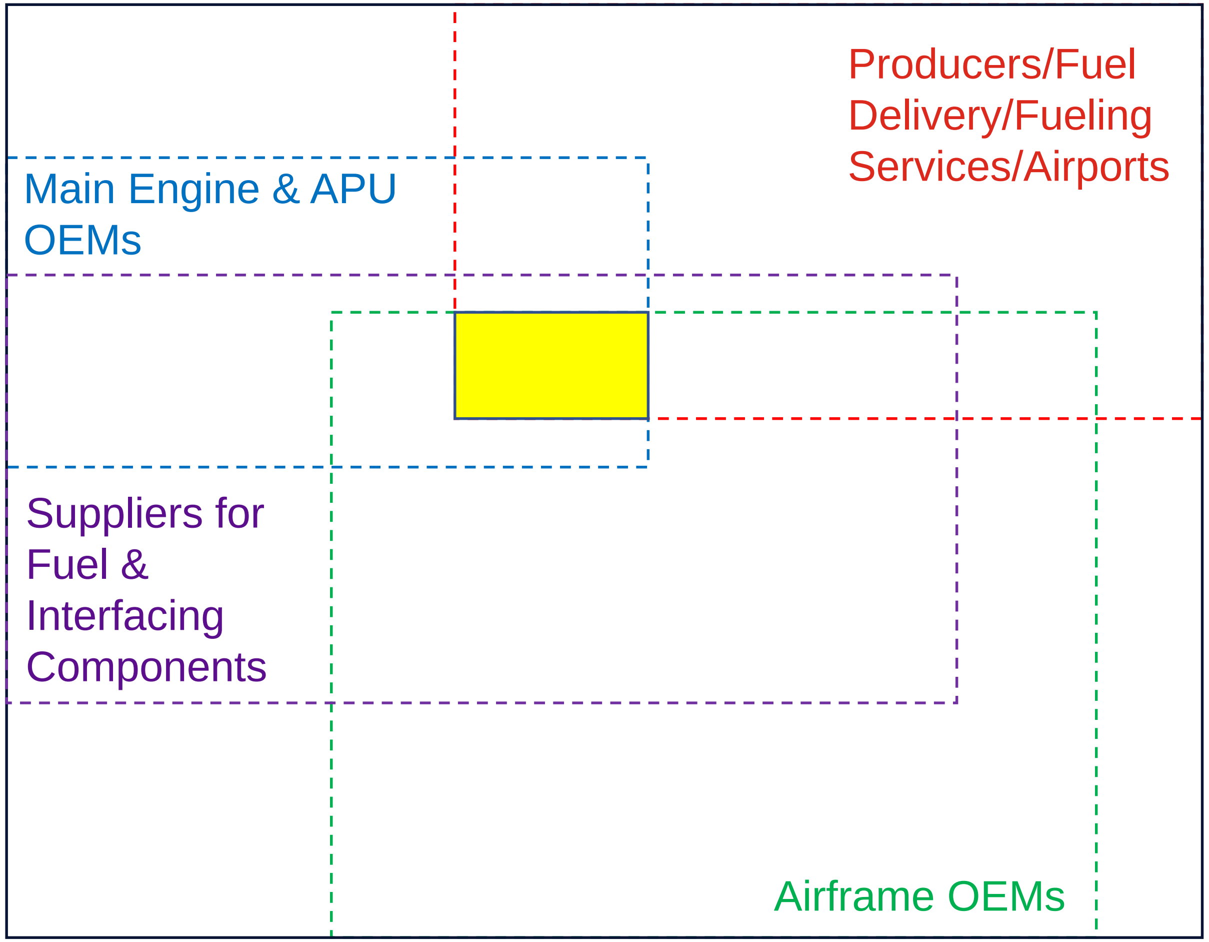
- Distillate products with carefully defined properties that target property of interest
    - Such JRFs are good candidates for engine testing

COPYRIGHT © BOEING 2023 • 

The outcome of evaluation testing by the involved OEMs and suppliers will define operating limitations leading to a **new fuel specification**

# Reference fuels & fully formulated fuels

Fuel properties envelope- performance and fit for purpose




- The historic approach to test with average Jet A, Jet A-1, JP-8, JP-5, TS-1, etc. is not going to work
- Need to test with fuels/test fluids that are at, or slightly exceed, borderline properties of interest

COPYRIGHT © BOEING 2023 

# FAA engagement and involvement

21.41
Type Certificate
(Type Design + Operating Limitations, Type Certificate Data Sheet, any other limitations)

Fuel is Part of the Type Certificate, But Not Part of the Type Design

21.31
Type Design
(Data Defining Configuration, Airworthiness Limitations, Noise/Emissions/Airworthiness Data)

33.7 & 25.1521
Operating Limitations
(Fuel specification, airspeed, gross weight, rated thrust, oil temp, etc. )

OEM Fuel Specification

COPYRIGHT © BOEING 2023 • 

# ASTM is the standards body

ASTM INTERNATIONAL
Helping our world work better

- ASTM D02.J0 (Aviation Fuels) establishes consensus-based fuel specifications and testing standards – industry participation
- Alongside UK MOD Def Stan, ASTM covers most of the world's commercial aviation fuel standards (ASTM D1655 à Jet A/A-1; Def Stan 91-091 à Jet A-1)
- The major regulators (FAA, EASA, etc.) fully delegate this authority to ASTM and Def Stan.
- For SAF, two general ASTM specifications are in play: D4054 & D7566

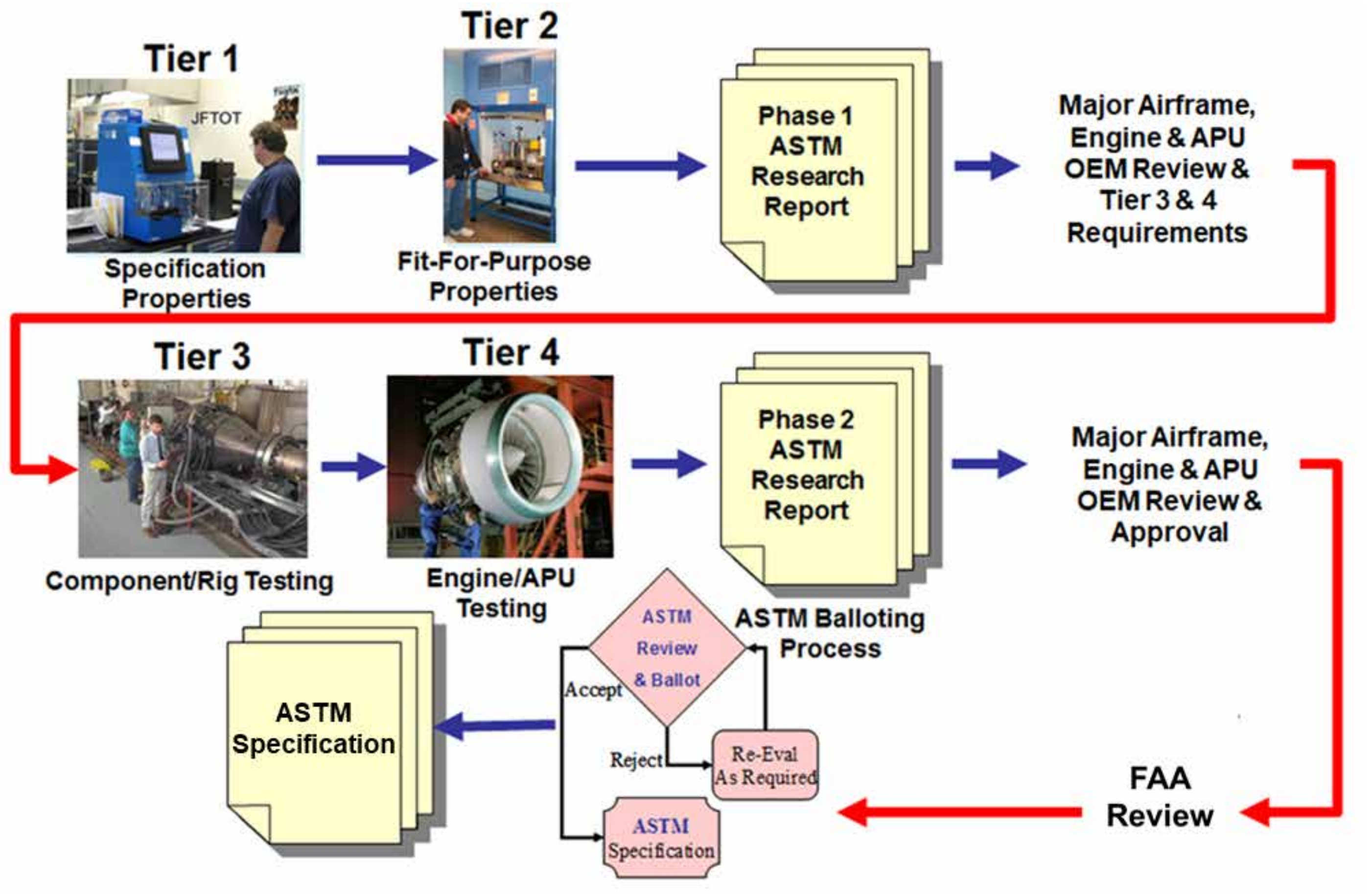
| | | |
|---|---|---|
| D4054 | ***Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives*** | Provides multi-tiered testing and analysis guidelines for fuels to be authorized under D7566 |
| D7566 | ***Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*** | Provides the synthetic fuel property requirements that, once met, are considered fully conforming to D1655 (Jet A). Has several annexes that list the specifically-approved SAF formulations and blend limits. |

# FAA engagement and involvement

Designation: ASTM D4054

"Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives"

- Close interaction between the FAA and OEM group
- the FAA fuel specialist is actively engaged in fuel approvals



# 100% SAF ASTM TASK FORCES

# AC598 Standardization of Jet Fuel Fully Comprised of Synthesized Hydrocarbons
Created: March 24, 2021 11:24:11 AM

***Collaboration Area Objective***
*There is peaked interest in the aviation industry to adopt sustainable aviation fuels in support of achieving the aggressive climate targets. Although not immediate, the need to utilize SAF at blend ratios above those currently allowed, and even at 100%, will come in not-too-distant future. This Task Force will address this challenge and work towards standardization of jet fuel fully comprised of synthesized hydrocarbons.*

# AC681 100% Non Drop-In Synthetic Aviation Jet Fuel (SAF)
Created: April 12, 2022 7:16:01 AM

***Collaboration Area Objective***
*To develop testing protocols and limitations for the development of 100% SAF that is not a drop in fuel.*

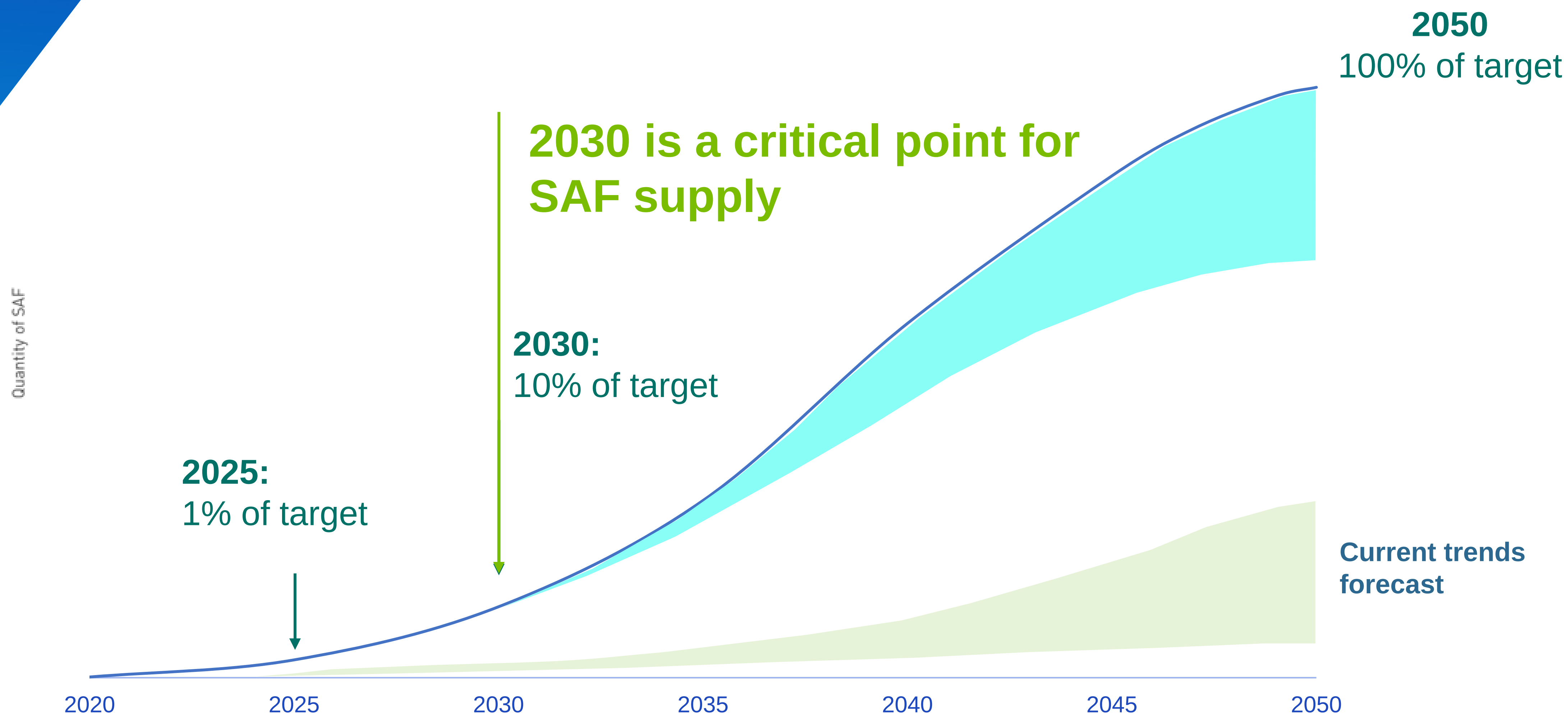
COPYRIGHT © BOEING 2023 • 


Table of Contents



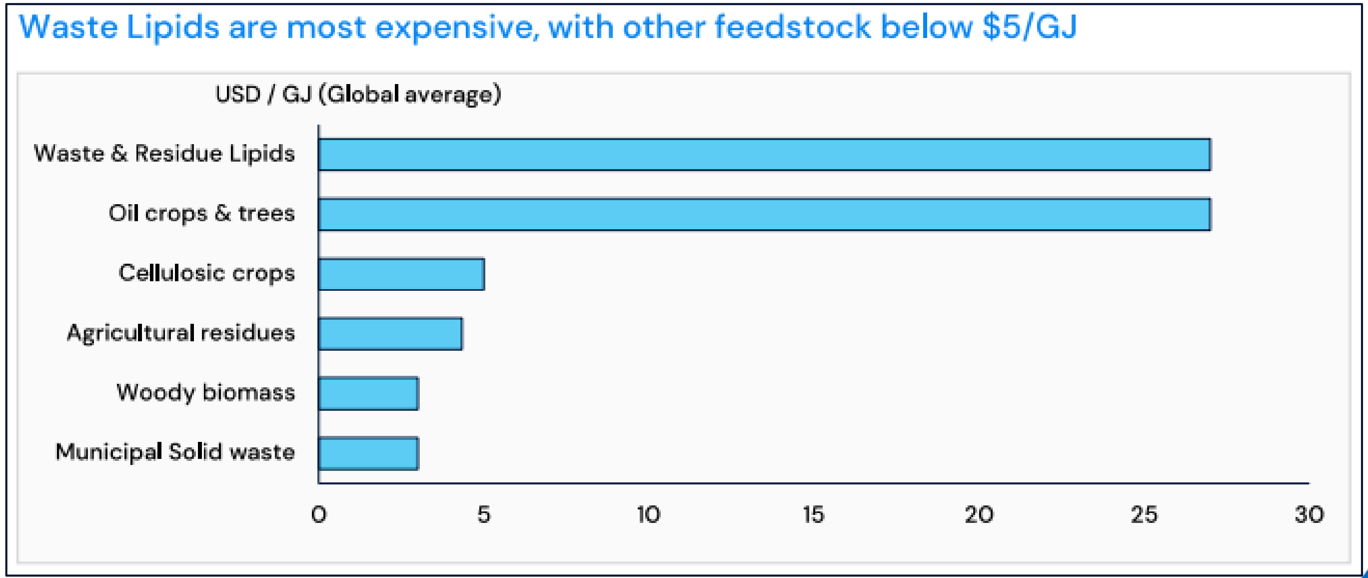
COPYRIGHT © BOEING 2023 

# SAF needs to grow exponentially to reach 2050 target




Source: ATAG Waypoint 2050 Report

# Feedstock costs significantly drive SAF prices




- Feedstocks costs are driven by production costs and demand.
- UCO (waste lipid) hit record highs during the pandemic.

https://aviationbenefits.org/media/167495/fueling-net-zero_september-2021.pdf

# Conversion of feedstocks follow ASTM standards

| ASTM REFERENCE | CONVERSION PROCESS | Blend (up to) |
|---|---|---|
| ASTM D7566 Annex 1 | **FT -** Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene | 50% |
| ASTM D7566 Annex 2 | **HEFA -** Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids | 50% |
| ASTM D7566 Annex 3 | **SIP-** Synthesized iso-paraffins from hydroprocessed fermented sugars | 10% |
| ASTM D7566 Annex 4 | **FT-SKA -** Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources | 50% |
| ASTM D7566 Annex 5 | **ATJ-SPK -** Alcohol to jet synthetic paraffinic kerosene | 50% |
| ASTM D7566 Annex 6 | **CHJ -** Catalytic hydro-thermolysis jet fuel | 50% |
| ASTM D7566 Annex 7 | **HC-HEFA-SPK -** Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids | 10% |
| ASTM D1655 Annex A1 | **Co-processed HEFA -** Co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery | 5% |
| ASTM D1655 Annex A1 | **Co-processed-FT -** Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery | 5% |

COPYRIGHT © BOEING 2023 • 

# Feedstock certification is tied to sustainability requirements

- Legality
- Planning, Monitoring, and Continuous Improvement
- Lifecycle Greenhouse Gas Emissions
- Human & Labor Rights
- Rural & Social Development
- Local Food Security
- Conservation and Soil Health
- Water & Air Quality
- Use of Technology, Inputs & Management of Waste
- Land Rights

https://rsb.org/about/what-we-do/the-rsb-principles/

# Act Regionally, Benefit Globally

- Most feedstocks favor regional sourcing, production, and use to limit transport costs and it helps local and regional economies
- GHG effects are local, regional, and global; the use of SAF anywhere advances us to net zero carbon by 2050



Table of Contents



COPYRIGHT © BOEING 2023 

Working in partnership is the Boeing approach to getting SAF into daily use.

It really does take a village.

# Keys to accelerating sustainable aviation fuel supply growth

**Supportive government policies**

**Feedstock diversity & robust sustainability criteria**

**R&D to enable cost competitiveness & supply growth**

**Access to capital for new production**

**Market-based incentives to make SAF price competitive**

Copyright © 2023 Boeing. All rights reserved

BOEING